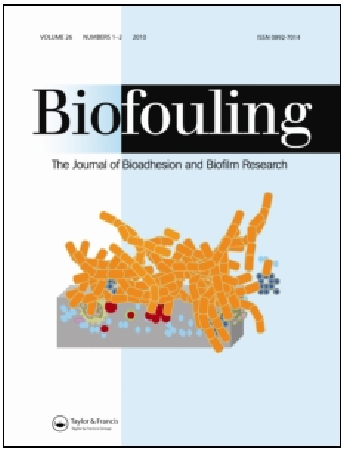

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A preliminary assessment of biofouling and non-indigenous marine species associated with commercial slow-moving vessels arriving in New Zealand

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Vessel traffic is the primary pathway for non-indigenous marine species introductions to New Zealand, with hull fouling recognised as being an important mechanism. This article describes hull fouling on seven slow-moving commercial vessels sampled over a 1 year period. Sampling involved the collection of images and fouling specimens from different hull locations using a standardised protocol developed to assess vessel biofouling in New Zealand. A total of 29 taxa was identified by expert taxonomists, of which 24% were indigenous to New Zealand and 17% non-indigenous. No first records to New Zealand were reported, however 59% of species were classified as 'unknown' due to insufficient taxonomic resolution. The extent of fouling was low compared to that described for other slow-movers. Fouling cover, biomass and richness were on average 17.1% (SE = 1.8%), 5.2 g (SE = 1.1 g) and 0.8 (SE = 0.07) per photoquadrat (200 × 200 mm), respectively. The fouling extent was lowest on the main hull areas where the antifouling paint was in good condition. In contrast, highest levels of fouling were associated with dry-docking support strips and other niche areas of the hull where the paint condition was poor. Future studies should target vessels from a broader range of bioregions, including vessels that remain idle for extended periods (ie months) between voyages, to increase understanding of the biosecurity risks posed by international commercial slow-movers.

Keywords: barge; biological invasion; hull fouling; shipping; tug

Introduction

Hull fouling is a feature of all maritime vessels, and has been implicated in the global spread of non-indigenous species (NIS) since international vessel traffic began (Bishop 1951; Carlton and Hodder 1995 and references therein). Hull fouling is also recognised as an important modern-day pathway for the human-mediated spread of NIS (Dafforn et al. 2008; Piola and Johnston 2008; Yamaguchi et al. 2009; Coutts et al. 2010), especially with a global ban on the use of highly effective organotin-based antifouling (AF) coatings (Nehring 2001; Champ 2003; Yebra et al. 2004; Sonak et al. 2009). Several studies have characterised biofouling on merchant ships, international fishing vessels and international yachts (eg Coutts and Taylor 2004; Coutts and Dodgshun 2007; Davidson et al. 2009; Piola and Conwell 2010), but much remains to be understood about predictors of biofouling and NIS transfer.

Increasingly, commercial vessels such as barges and their tugs have also been recognised as high risk pathways for the spread of NIS (Lewis et al. 2006; Coutts et al. 2010), and in some cases identified or implicated in the international and domestic spread of some high-profile marine pests (Coutts and Forrest 2007). Like merchant vessels and yachts, the condition of AF coatings is a factor that is expected to affect the susceptibility of barges and tugs to fouling. However, the operational profile of craft such as barges means they are often stationery for long periods, which will decrease the efficacy of their AF coatings due to lower biocidal release rates and lead to an accumulation of biofouling organisms (Ferreira et al. 2006). Moreover, the slow speed at which such vessels travel (cruising speed of 5–10 knots) is likely to favour the survival of their associated fouling assemblages (Davidson et al. 2006; Coutts et al. 2010).

The international movement of barges and tugs provides an interesting addendum to an understanding of the biosecurity risk from vessel hull fouling. While it is apparent that merchant vessels are numerically the dominant international vessel type, comprising *ca* 75% of international traffic to New Zealand (MAF Biosecurity New Zealand (unpublished data)), the incidence of fouling on such vessels is typically low (Coutts and Taylor 2004). This reflects the fact that merchant vessels are largely in constant use and well-maintained to improve hydrodynamic efficiencies (Coutts and Taylor 2004; Schultz 2007). In contrast, barge and tug movements internationally are considerably less in number, but have the potential to be heavily fouled. In

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New Zealand, for example, a poorly maintained and heavily fouled barge was identified as the vector by which the invasive colonial ascidian *Didemnum vexillum* was transferred into a nationally important aquaculture region (Coutts and Forrest 2007).

The above and other examples of extensive fouling on international (eg Davidson et al. 2008a,b) and domestic (eg Coutts 2002) slow-moving vessels clearly highlight the potential biosecurity risk that arises with the movement of such craft. However, from the literature it is unclear whether such examples are representative of a biosecurity risk generally, as there appear to have been no systematic surveys of fouling on operational international slow-moving commercial vessels. Hence, this article provides a preliminary characterisation of the extent of fouling and the occurrence of non-indigenous marine species on commercial barges and tugs arriving in New Zealand over a 1 year period.

Methods

Description of vessels sampled

Five barges and two tugs were sampled at four New Zealand ports between May 2006 and May 2007. All vessels surveyed had arrived from Australia and had been operating on New Zealand – Australia routes. Although tugs can travel at > 10 knots, they were included in the sampling because they travel at slow speeds (*ca* 5 knots) when towing, and often remain idle with their barge while not underway. Five of the vessels were sampled on one occasion only. However, repeat visits by the tug Katea (May and August 2006, May 2007) and the barge Sea-Tow 60 (September 2006 and May 2007) enabled a preliminary evaluation of changes in fouling over time. Thus, during the 1 year study period, a total of 10 vessels were sampled from an estimated 31 barge and tug arrivals in New Zealand (Sea-Tow Ltd (unpublished data)). While sampling only accounted for approximately one-third of slow-mover arrivals, it nonetheless captured a high proportion of unique vessel visits (85% and 67% for barges and tugs, respectively) due to repeat visits by the same vessels (ie 4 vessels accounted for 81% of total slow-mover traffic).

Barges sampled ranged in length from 47 to 97 m (beam = 8.9 and 24.0 m, respectively), while tugs ranged from 29 to 34 m (beam = 9.0 and 10.8 m, respectively). Vessel speeds (while towing or being towed) ranged from 5 to 7.5 knots (Table 1). All Sea-Tow vessels had ablative AF coatings (Sea-Barrier 3000^{TM}). The barges Soundcem I and Soundcem II also had an ablative AF coating, but the owners could not specify which paint brand. None of the vessels sampled during this study had been cleaned in-water since their last dry-docking. Residency periods ranged from 1 to 37 days (based on the previous 20 ports visited before sampling), with a slightly higher average residency period for barges (mean = 5.0 days, SE 0.8 days) compared with tugs (mean = 3.4 days, SE = 0.6).

Vessel sampling procedures and determination of fouling extent

Hull fouling on each vessel was assessed using a standard sampling protocol developed for international yacht arrivals to New Zealand (Floerl et al. 2005) and later applied by Ministry of Agriculture and Forestry (MAF) Biosecurity New Zealand for assessing fouling across a range of international vessel types. First, a level of fouling (LoF) rank (0–5) was assigned based on surface (ie out of water) observations along the length of the vessel, as follows: 0 = no visible fouling, 1 = partial biofilm, 2 = 1–5% of patchy macrofouling or filamentous algal cover,

Table 1. Summary information, maintenance history and residency periods for each of the vessels surveyed.

Vessel name	Date sampled	Location sampled (latitude)	Average speed (knots)	Length/beam/ draft (m)	Time since last dry dock	Average residency period – days (SE)
Tugs						
Katea (1)	25/05/2006	Auckland (36°S)	6.0	29.0/9.0/3.5	11 months	2.8 (1.0)
Koranui	7/06/2006	Tauranga (37°S)	7.5	34.4/10.8/5.6	1 year 3 months	5.3 (1.8)
Katea (2)	29/08/2006	Westport (41°S)	5.5	29.0/9.0/3.5	1 year 2 months	2.1 (0.2)
Katea (3)	10/05/2007	Nelson (41°S)	6.5	29.0/9.0/3.5	1 year 11 months	3.4 (1.2)
Barges						
Soundcem II	25/05/2006	Auckland (36°S)	6.0	47.0/8.9/2.8	1 month	30
Soundcem I	25/05/2006	Auckland (36°S)	6.0	47.0/8.9/2.8	1 month	30
Sea-Tow 80	7/06/2006	Tauranga (37°S)	7.5	97.0/24.0/4.8	6 years, 1 month	5.3 (1.8)
Sea-Tow 61	29/08/2006	Westport (41°S)	5.5	85.3/24.4/5.5	1 year 9 months	2.1 (0.2)
Sea-Tow 60 (1)	28/09/2006	Nelson (41°S)	6.0	85.3/24.4/5.5	1 year 10 months	7 (1.8)
Sea-Tow 60 (2)	10/05/2007	Nelson (41°S)	6.5	85.3/24.4/5.5	2 years 6 months	3.4 (1.2)

None of the vessels had been in-water cleaned since dry-docking.

$3 = 6–15\%$ patchy cover, $4 = 16–40\%$ cover and $5 = >40\%$ fouling cover. For comparison with surface observations, divers recorded in-water LoF at the same vessel regions without prior knowledge of the surface scores assigned.

Divers then took photoquadrats (200 $\times$ 200 mm) at four vessel regions (Figure 1), ie the bow, amidships, stern and opportunistically sampled niche areas (eg gratings, propeller shaft), using an 8 megapixel Canon EOS digital camera (18–55 mm lens kit, Ikelite^{TM} underwater housing, 2 $\times$ Ikelite^{TM} DS50 strobes). Sampling within the bow, amidships and stern regions was conducted in zones, with replicate ($n = 3$) samples haphazardly taken near-surface (0.5 m), inside dry-docking support strips (DDSS) (where feasible), and on sub-surface areas of the hull where AF paint was present. For each photoquadrat, divers assessed paint condition as good (no imperfections), average (minor chipping and visible paint wear to base layers) or poor (substantial areas of no paint, and/or bare hull). Organisms within the quadrat were scraped into labelled sample bags. At the surface, samples were sieved to 1 mm, blotted, weighed, sorted into broad taxonomic groups and preserved. Samples were identified to the highest level of taxonomic resolution feasible by specialist taxonomists and classified as being either native (indigenous), non-indigenous, cryptogenic (uncertain origins) or unknown (due to insufficient taxonomic resolution).

At the completion of sampling, photoquadrats were rectified in ArcMap 9.2 (ESRI, Redlands, CA, USA). Fouling biota present within each image were individually traced to create a map from which per cent cover of fouling could be calculated by dividing the total area of fouling taxa by the quadrat area and multiplying by 100. Fouling richness was determined as the number of different taxa within each photoquadrat image. Fouling biomass was expressed as wet weight of the blotted samples.

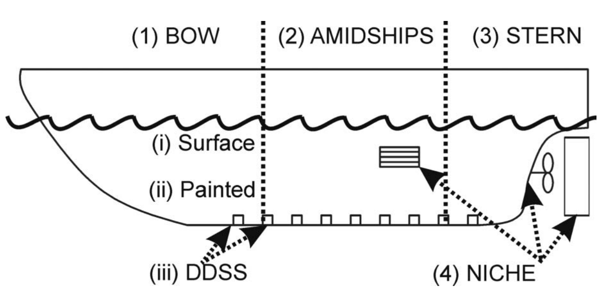

Figure 1. Diagram of a vessel hull identifying vessel regions (1–4) and vertical sampling zones (i–iii). Opportunistically sampled areas of a vessel hull typically included gratings, propeller shafts, seawater intake pipes and behind anodes; however these were not always present on the vessels sampled.

Statistical analyses

Given the low vessel sample size, data analyses were restricted to descriptive statistics for the quantitative measures of fouling extent and qualitative assessments of paint condition, and categorical levels of fouling. Relationships between fouling extent (% cover, biomass and richness) and categorical levels of fouling (LoF) were tested using one-way ANOVA. Data were explored for homogeneity and normality using Statistica Version 7 (StatSoft Inc., Tulsa, OK, USA), and dependent variables were $\log(x + 1)$ transformed where necessary to meet the assumptions of generalised linear modelling. Differences between surface and diver observations of fouling were tested using the non-parametric Wilcoxon match pairs test. For these analyses, data from repeat sampling events of the same vessel were excluded.

Results

Antifouling paint condition

Paint condition on the seven vessels was consistently rated as poor in opportunistically sampled niche areas (eg sea chests, gratings) and on the dry-docking support strips (DDSS) where paint had not been applied during the previous dry-docking event. Paint condition on the main hull surface of the tugs was rated as good for 100% of the 36 observations, but barges were assigned a higher proportion of poor (11%) and average (17%) scores. In particular, the barge Sea-Tow 80 ($>$ 6 years since last dry-dock) had poor paint condition present on all sub-surfaces inspected. There was also a higher proportion of average and poor paint scores assigned to surface sampling zones ($\sim$ 1 m below the waterline) for both barges (8.3 and 8.3%, respectively) and tugs (6 and 9%, respectively).

Fouling identity, cover, biomass and richness

Twenty nine taxa were identified from 125 samples collected during the 1 year survey (Table 2). Of these, 41% were identified to species-level, 31% to genus-level and the remaining 28% to phylum. A relatively diverse range of taxa was encountered, representing four animal and four algal phyla (Figure 2). Samples were numerically dominated by arthropods (mainly crustaceans), molluscs and macroalgae. Approximately 24% of taxa were indigenous to New Zealand and 17% non-indigenous, and a high proportion of taxa (59%) had 'unknown' status due to insufficient taxonomic resolution (ie as a result of partial/damaged specimens or lack of distinguishing features in juveniles). Non-indigenous taxa were found on both barges

Table 2. Presence of taxa on vertical sampling zones and opportunistically sampled niche areas of slow-movers and their current biosecurity status in New Zealand.

Taxon	Description	Biosecurity status	Tug				Barge			
			Surface	Painted	DDSS	Niche	Surface	Painted	DDSS	Niche
Acryptolaria sp.	Hydroid	Status unknown							X	
Amphibalanus amphitrite	Acorn barnacle	Non-indigenous		X			X			X
Amphibalanus variegatus	Acorn barnacle	Indigenous		X	X	X	X	X	X	X
Anthozoa	Anemone	Status unknown						X		
Austrominius modestus	Acorn barnacle	Indigenous	X		X	X	X	X	X	X
Bangia sp.	Red alga	Status unknown	X							X
Bivalvia	Unid. Bivalve	Status unknown			X					
Cladophora sp.	Green alga	Status unknown	X							X
Conchoderma auritum	Goose barnacle	Indigenous			X	X				
Coryne pusilla	Hydroid	Non-indigenous							X	X
Crassostrea gigas	Oyster	Non-indigenous				X		X		
Crassostrea sp.	Oyster	Status unknown			X					
Cyanobacteria	Cyanobacteria	Status unknown								X
Ectocarpales	Brown algae	Status unknown	X				X			
Ectocarpus fasciculatus	Brown alga	Indigenous	X			X		X		X
Eudendrium sp.	Hydroid	Status unknown				X			X	
Hydrozoa	Unidentified hydroid	Status unknown			X			X	X	X
Lepas anatifera	Goose barnacle	Indigenous	X	X					X	
Maxillopoda	Unid. maxillopod	Status unknown			X		X		X	X
Mytilus galloprovincialis	Blue mussel	Indigenous			X				X	X
Obelia dichotoma	Hydroid	Non-indigenous								X
Obelia sp.	Hydroid	Status unknown							X	X
Ostreidae	Oyster	Status unknown						X	X	
Paracerceis sculpta	Isopod	Non-indigenous	X							
Polysiphonia sp.	Red alga	Status unknown	X							
Rhizoclonium sp.	Green alga	Status unknown	X							
Serpulidae	Calcareous tubeworm	Status unknown								X
Stylonema alsidii	Red alga	Indigenous								X
Ulva sp.	Green alga	Status unknown	X			X	X			X

X = present.

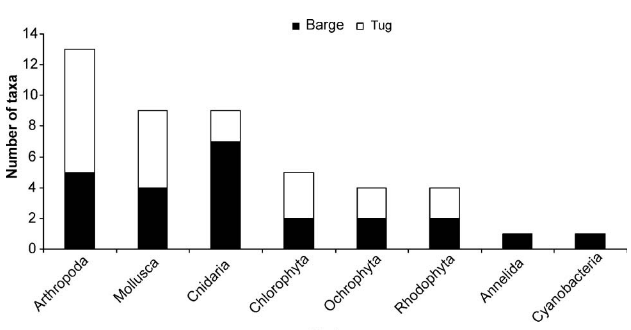

Figure 2. Number of taxa (assigned to phyla) on vessels surveyed.

and tugs; however, no first records for New Zealand were present in the samples taken (Table 2).

In general, fouling assemblages encountered on the vessels were two-dimensional in structure rather than well-developed, three-dimensional late successional stages. Fouling cover ranged from 0 to 100% (overall mean = 17%), with higher levels observed on tugs compared with barges (Table 3). Fouling cover did not vary greatly along the vessel regions (bow, amidships, stern and niche areas) for either vessel type. However, fouling cover on vertical sampling zones (ie surface, painted and DDSS) was more variable, with higher levels on the DDSS (where paint condition was poor)

Table 3. Mean fouling cover (%) and richness per photoquadrat (0.04 m^2) taken within vertical sampling zones (surface, painted, DDSS) across the vessel sampling regions (refer Figure 1).

Vessels	Bow			Amidships			Stern			Opportunistic Niche
	Surface	Painted	DDSS	Surface	Painted	DDSS	Surface	Painted	DDSS	
Cover (%)										
Tugs										
Katea (1)	100 (0)	0	7.9 (3.3)	100 (0)	0	0.2 (0.2)	0	0	0	0.2 (0.1)
Koranui	0	0	64.9 (20.4)	0	0	60.1 (14.1)	0	0	4 (0.18)	31.6 (11.8)
Katea (2)	100 (0)	0	39.0 (13.5)	100 (0)	0	0.2 (0.1)	100 (0)	0	0	44.7 (20.1)
Katea (3)	38.1 (7.6)	0	100 (0)	74.5 (9.6)	0	3.1 (2.2)	89.0 (4.7)	0	14.9 (6.7)	29.8 (15.5)
Barges										
Soundcem II	0	0	0	0	0	2.2 (1.5)	0	0	0.2 (0.1)	8.8 (5.1)
Soundcem I	0	0	0	0	0	2.8 (1.4)	0	0	0	81.5 (0)
Sea-Tow 80	1.5 (0.4)	0.4 (0.1)	1.0 (0.2)	3.3 (2.9)	24.9 (7.1)	8.7 (3.6)	0.02 (0.02)	5.0 (0.7)	0	11.5 (3.3)
Sea-Tow 61	0	0	2.6 (0.7)	0	0	2.8 (0.6)	0	0	0.1 (0.1)	6.1 (0.1)
Sea-Tow 60 (1)	0	0	65.1 (16.9)	0	0	82.9 (17.1)	52.5 (20.1)	0	63.8 (7.8)	36.6 (12.3)
Sea-Tow 60 (2)	0	0	79.7 (6.1)	0	0	84.7 (15.4)	0	0	0	24.7(0.1)
Richness										
Tugs										
Katea (1)	0	0	1 (0)	2.3 (1.2)	0	0.7 (0.7)	0	0	0	0.5 (0.4)
Koranui	0	0	1.3 (0.3)	0	0	1.0 (0)	0	0	1.0 (0)	2.0 (1)
Katea (2)	3.0 (0.6)	0	2.0 (0.6)	4.3 (0.3)	0	0	3.0 (0)	0	0	1.0 (0.4)
Katea (3)	2.0 (0)	0	3.5 (0.5)	2.0 (0)	0	0.7 (0.3)	2.0 (0)	0	1.0 (0)	2.5 (0.5)
Barges										
Soundcem II	0	0	0	0	0	1.0 (0.6)	0	0	0.7 (0.3)	1.7 (0.3)
Soundcem I	0	0	0	0	0	1.7 (0.3)	0	0	0	1.0 (0)
Sea-Tow 80	1.0 (0)	1 (0)	1.0 (0)	2.7 (0.9)	2.7 (0.3)	2.7 (0.3)	0.3 (0.3)	1.3 (0.3)	0	1.0 (0.2)
Sea-Tow 61	0	0	3.0 (0)	0	0	1.0 (0)	0	0	0.3 (0.3)	1.0 (0)
Sea-Tow 60 (1)	0	0	2.0 (0)	0	0	2.0 (0)	0	0	2.0 (0)	3.8 (1.2)
Sea-Tow 60 (2)	0	0	2.3 (0.3)	0	0	2.6 (0.3)	0	0	0	3.0 (0)

Associated SE (bracketed values) is shown.

compared with painted areas of the hull. Taxon richness per photoquadrat on barges and tugs was very low (mean = 0.89 and 0.8 taxa, respectively). Overall vessel taxon richness ranged between 3 and 10 taxa for barges (mean = 8.5, SE = 1.3), and 6 and 12 for tugs (mean = 7.0, SE = 1.2). Fouling biomass ranged between 0 and 4.4 kg m^{-2} (overall mean 0.13 kg m^{-2}, SE = 0.03 kg m^{-2}), with highest levels observed on DDSS (mean = 0.3 kg m^{-2}, SE = 0.1 kg m^{-2}) and on niche areas (mean = 0.3 kg m^{-2}, SE 0.05 kg m^{-2}) of the vessels.

Samples collected opportunistically from niche areas of the vessels where paint condition was typically poor, were often characterised by higher taxon richness (Tables 2 and 3), including fouling taxa typically associated with later stages of fouling (eg bivalves). In contrast, painted areas of the vessel hulls had low richness with mainly barnacles and hydroids present. Surface zones were characterised by a high incidence of macroalgae. Dry-docking support strips (ie where AF paint was absent) had a diverse range of taxa present (eg barnacles, bivalves and hydroids), with macroalgae noticeably absent within this zone (Table 2).

Fouling characteristics on vessels sampled more than once during the 1 year sampling period changed over time. For Katea, changes in fouling are evident as marked differences in % cover, taxa richness and biomass between sampling events (Figure 3). Of particular note was the pronounced increase in average fouling cover and taxa richness over a 3 month period between the first two sampling events, and the large increase in fouling biomass over the 1 year period between the second and third sampling events.

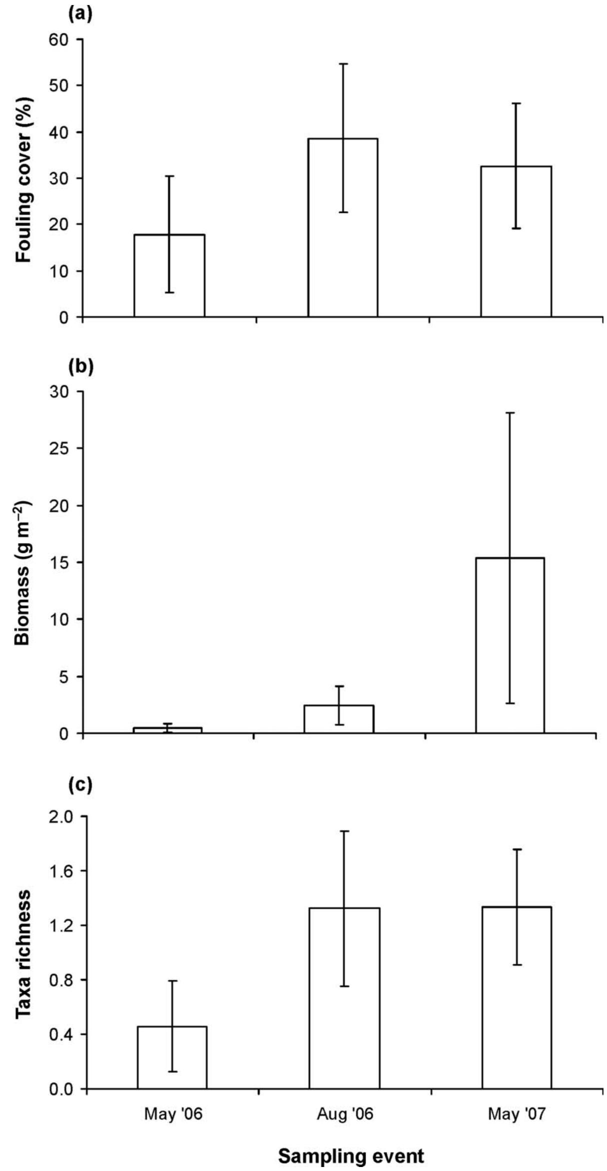

Figure 3. Changes in mean (a) fouling cover, (b) fouling biomass and (c) taxa richness per photoquadrat on the tug Katea over the three separate sampling events (time since last dry-docking = 11, 13 and 21 months) undertaken over the 1 year study period. Error bars denote 95% confidence intervals.

Utility of LoF as a measure of fouling

Strong positive linear relationships were evident between categorical level of fouling (LoF) scores assigned by divers and quantitative measures of fouling cover ($F_{4,297} = 54.74$, $P < 0.001$) and taxon richness ($F_{4,297} = 119.25$, $P < 0.001$). Fouling biomass also increased with increasing LoF ($F_{2,297} = 37.83$, $P < 0.001$). However, this relationship was non-linear (exponential), with a marked increase in biomass at LoF scores ≥ 3 (Figure 4).

Given the relative ease in which surface scores for LoF can be assigned, it was of interest to determine whether they corresponded to the LoF below the surface of the vessel. As expected, there was no significant difference between LoF values assigned at the surface by non-divers and by divers (Wilcoxon match pairs test, $Z = < 0.01$, df = 63, $P = 1.00$). However, surface observations of fouling were unable to reliably predict fouling levels on painted areas of the vessel below the waterline ($Z = 4.29$, df = 63, $P < 0.001$), on DDSS ($Z = 5.18$, df = 56, $P < 0.001$) or on opportunistically sampled regions of the hull ($Z = 4.22$, df = 34, $P < 0.001$).

Discussion

Fouling composition and patterns

Biofouling on commercial slow-movers arriving in New Zealand over the 1 year study period was neither taxon rich nor extensive, and comparable to that

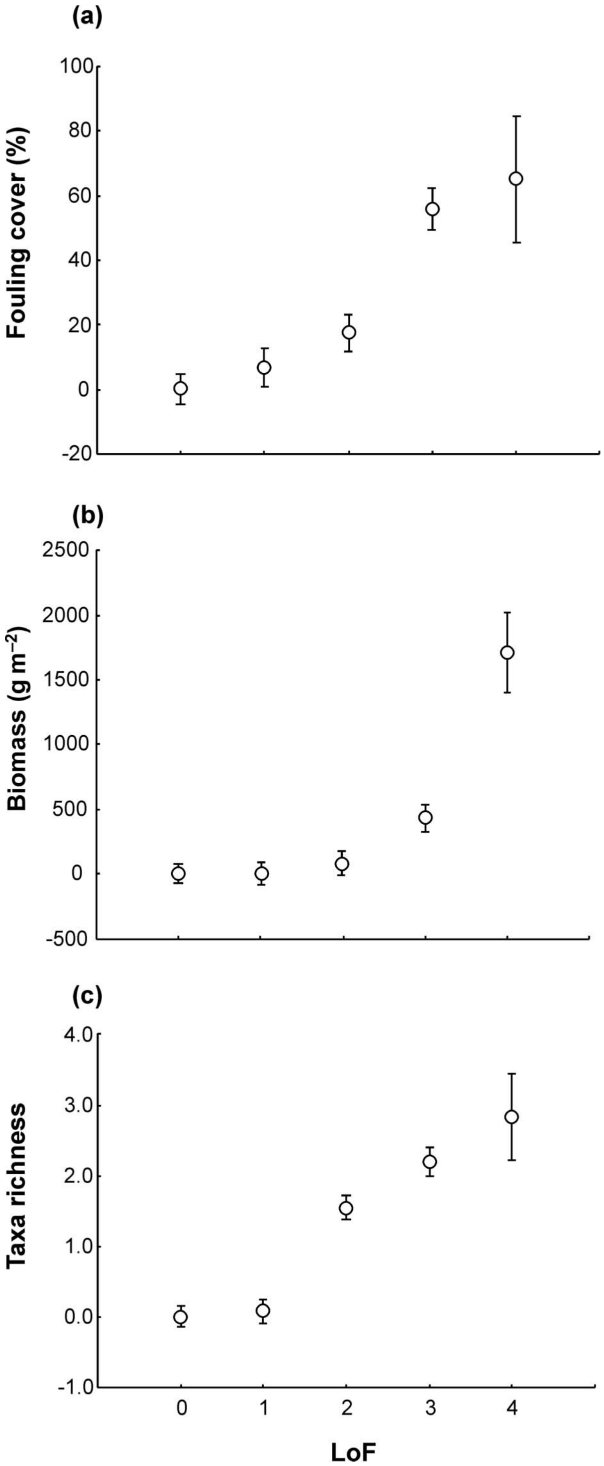

Figure 4. Categorical levels of fouling (LoF) and corresponding (a) fouling cover, (b) biomass and (c) taxa richness. Error bars denote 95% confidence intervals.

described for merchant vessels visiting New Zealand (Coutts and Taylor 2004). A low incidence of fouling was also described on cargo barges arriving in Hawaii (Godwin 2003; Godwin et al. 2004), yet some fouling studies on slow-movers have described extensive and/or diverse biofouling communities (eg Lewis et al. 2006; Coutts and Forrest 2007).

Observations of low fouling extent in the present study were most likely due to the fact that most vessels were sampled within 2 years of their most recent AF coating (average of *ca* 2 years for barges and *ca* 16 months for tugs). Furthermore, vessels typically spent short periods of time idle between voyages (ie 85% of port visits were <5 days), thus the window of opportunity for colonisation and growth by local taxa was considerably less than that of vessels with long residency periods (eg obsolete vessels, Davidson et al. 2008b).

It appears for slow-moving vessels that locational differences are likely to be less pronounced than observed on faster moving vessels such as merchant ships (speeds $>$ 20 knots), for which fouling is greater in hydrodynamically protected areas (Coutts et al. 2003; Coutts and Taylor 2004). Conceivably, the forces on a vessel moving at slow speeds (*ca* 5 knots) are not sufficient to adversely affect (eg dislodge, damage) fouling assemblages, such that patterns of fouling across the hull are independent of location. However, the observation of higher fouling on DDSS and niche areas is consistent with most other vessel hull fouling studies (eg Godwin and Eldredge 2001; Coutts and Taylor 2004; Coutts and Dodgshun 2007; Davidson et al. 2009), and is intuitive given that the AF paint was generally in poor condition and was unlikely to contain sufficient active biocides to prevent colonisation by the planktonic propagules of fouling biota (Coutts and Taylor 2004). Thus, these vessel regions prone to accumulate fouling probably pose the greatest biosecurity risk because they tend to have the greatest number of taxa present (Coutts and Taylor 2004; Davidson et al. 2009).

Surface observations of fouling on the vessels did not appear to be a useful predictor of sub-surface fouling, given that they did not reliably predict fouling levels on painted and unpainted (ie dry-docking support strips) surfaces of the hull, nor niche areas (eg gratings, intake pipes and anode straps). Essentially, high levels of fouling can occur in niche areas, despite low fouling visible from surface inspection. As niche areas may be of most significance from a biosecurity perspective, a reliable assessment of risk will generally need to be based on in-water inspection rather than surface observation alone. On the other hand, it was noted that high surface fouling will generally reflect a vessel that is heavily fouled overall (eg Coutts and Forrest 2007; G. Hopkins, personal observation), hence surface-based observation can justifiably be used to identify 'rogue' vessels that often present a high biosecurity risk (eg Piola and Forrest 2009).

Biosecurity risks from NIS on slow-moving commercial vessels

The low number of NIS (5 taxa) encountered on the seven vessels sampled in the present study were globally ubiquitous and none were first time records in New Zealand. By comparison, there are some 2000 international merchant vessel visits per year (Dodgshun et al. 2007), for which recent studies indicate a relatively high occurrence of NIS and cryptogenic species (*ca* 4 per vessel) (Inglis et al. 2010). Hence, merchant vessels conceivably represented a far greater biosecurity risk to New Zealand over the study period.

Nonetheless, the risk from the slow-movers sampled in the present study cannot be dismissed as trivial, as a large proportion (*ca* 59%) of taxa sampled were unknown. Past experience shows that the translocation of relatively unknown species with no history of invasiveness can lead to significant problems. In New Zealand, this was highlighted in 2001 when an unknown didemnid ascidian (later identified as *Didemnum vexillum*; Kott 2002) was discovered on a barge that had been moored for several months was heavily-fouled (Coutts and Forrest 2007). This species subsequently spread from the barge and is now a fouling pest to aquaculture (Pannell and Coutts (unpublished data)).

Although the data are preliminary, repeat sampling in the present study also showed how fouling can change (eg biomass increases) over time, conceivably reflecting decreased invasion resistance with age of AF paint. While greater fouling may be associated with a greater biosecurity risk, risk is also related to voyage history and the interaction between vessels and source populations of NIS (Floerl and Inglis 2005). A recent example highlighting this point was the discovery of a large number (*ca* 700) of Mediterranean fanworms (*Sabella spallanzanii*) on the barge Sea-Tow 80 during diver surveys in Auckland Harbour (November 2009). Sea-Tow 80 was sampled in the present study (July 2006) $>$ 6 years after being dry-docked, but had relatively low levels of hull fouling comprising solely indigenous taxa. The barge was then dry-docked in August 2006 (ie 1 month after the sampling for this study) and worked in Australia and New Zealand over the following 3 years. This voyage history included Port Phillip Bay, where there are established populations of *S. spallanzanii* (Hewitt et al. 2004). Hence, there is clearly a range of complex factors that must be considered in order to understand vessel risk.

A number of other examples similarly highlight the potential for a significant biosecurity risk to arise from the international movement of fouled tugs and barges (Lewis et al. 2006), oil rigs (Foster and Willan 1979; Hopkins and Forrest 2009) and other towed structures (DeFelice 1999; Apte et al. 2000). This situation parallels the recognised biosecurity risk posed by slow-moving recreational vessels such as yachts (Floerl and Inglis 2005; Piola and Forrest 2009; Inglis et al. 2010).

Conclusions

There will always be stochastic processes that determine vessel fouling and related risk from NIS. However, further sampling of commercial slow-movers will improve ability to predict fouling status and NIS risk profiles. Vessels from a broad range of bioregions and service industries should be targeted, for this purpose, in particular vessels that remain idle for extended periods between voyages (eg months rather than days/weeks as in the present study). Although there appear to be very few documented cases in which NIS transported by slow-movers have led to adverse effects in a recipient region, the potential nonetheless exists for these low likelihood events to have high consequences. On the basis that commercial slow-mover movements are only a fraction of global vessel movements, several management options are conceivable. In the New Zealand case, the very low number of slow-moving vessel arrivals each year makes it feasible to assess vessel risk on a case-by-case basis prior to their entry into the country, and to implement appropriate mitigation strategies (eg inspections for NIS and treatment where necessary) pre-border.

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